Experimental Set-up for Whole-Body SAR Estimation Based on Cylindrical Scanning of External Electric Field Distribution

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1. Introduction

The aim of this study is to achieve experimental estimation of whole-body averaged specific absorption rate (SAR) of human models using the radiation-field scanning technique. The relationship between the reference level of ICNIRP Guidelines [1] and the whole-body averaged SAR was established mainly based on numerical calculations for highly simplified human modelling. Recently, many dosimetry estimations for human exposure including high accuracy numerical phantom models have been reported [2]. However, due to the difficulty of the measurement in the whole human body exposed by RF plane-wave, there have been a few experimental investigations based on calorimeter or thermography method [3]. It is very important to obtain reliable measurement data that can contribute to validity analyses for the recent precise computational estimations. Previously, we proposed a new whole-body averaged SAR estimation method based on electric power consumption based on the cylindrical field scanning technique [4]. In this paper, we develop the experimental set-up for whole-body averaged SAR estimation using human phantom made of tissue-equivalent material and scaled model. Additionally, measured results of whole-body averaged SAR of standing human for 2GHz far-field exposure are shown.

2. Principle of Proposed Whole-Body SAR Estimation Method

A whole-body averaged SAR method which is based upon the power balance between exposed RF power and absorption power on the human body is proposed (Figure 1). In this method, the absorbed power (W_{ab}) due to the human phantom is obtained by estimation both of the outward radiated electric power (W_{out}) from the arbitrary closed area including the human phantom and the power (W_{in}) of the exposure plane wave. The total absorption power of the human is obtained by the following expression:

$$W_{ab} = W_{in} - W_{out} \qquad (1)$$

The input and output power of the closed area is obtained using Poynting vector S (W/m^2) based on the electromagnetic fields distributions measured on the boundary surface. The radiation power from the closed surface is obtained as follows:

$$W_{out} = \oint_S \mathbf{S} \cdot \mathbf{n} dS \qquad (2)$$

Then, the whole-body averaged SAR can be derived from the absorption power (W_{ab}) and weight of the human phantom.

$$\text{Whole body Averaged SAR} = \frac{W_{ab}}{\text{Weight}} \qquad (3)$$

To confirm the validity of the proposed method, we compared the whole-body average SAR of the proposed method with results obtained using the standard calculation method using Finite-Difference Time-Domain (FDTD) calculations [5]. The computation results suggested that it was possible to derive the averaged SAR of the whole body by using the proposed method and applicability of cylindrical scanning method was demonstrated.

For the electromagnetic field scanning, three major approaches, planar, cylindrical and spherical, have been used. The technique used most often is spherical scanning. However, it complicates the experimental setup needed here since a spherical scanning system requires a very large estimation space and the measured object should be suspended in midair. Cylindrical scanning is suitable since it simplifies the experimental setup. Then, the equation (2) is redefined for cylindrical scanning as follows:

$$W_{out} = \oint_S \mathbf{S} \cdot \mathbf{n} dS = \sum_{dz=0}^{Nz} \sum_{dp=0}^{Np} Sr \ dS \qquad (4)$$

3. Design and Development of Experimental Setup

In this study, the set-up assumes that the standing human exposed to a 2 GHz E-polarized plane wave. The power density of the plane wave is 1 mW/cm^2. To estimate plane-wave exposure at mobile radio frequencies on the human body, the direct approach is to use a full-size model. Instead, this study uses a scaled model. In an evaluation system that includes lossy materials such as the human phantom, both the electric constant and the scale of the lossy material should change. In this paper, a 1/2 scale model is used. The experimental set-up for the whole-body averaged SAR evaluation is shown in Figure 2 and 3. The radiation power from the cylindrical closed surface is obtained by electric field distribution measurement using 3-axis optical field sensor. The sampling interval of cylindrical scanning is 20 mm in height and 1 degree in circumference. The plane-wave exposure equipment which can generate almost uniform plane-wave on exposure area consists of dielectric lens and horn antenna. The human phantom is separated by 0.5 m from the lens of the exposure equipment. The physical human phantom is made based on an enhanced high-resolution European human CAD data [6]. A 34-year-old male adult model is used. Its height is about 1.74 m and 70 kg in weight. The human phantom is composed of 2/3 muscle-equivalent tissue [7]. The phantom used in this study consists of carbon nanotubes embedded in silicone rubber [8]. The phantom parameters are summarized in Table 1.

4. Results and Conclusions

An example of the field distributions on the cylindrical scanning area is shown in Figure 4. The whole-body averaged SARs are calculated using the weight of the human phantom model. The measured absorption power and whole-body averaged SAR estimation results are shown in Table 2 compared with FDTD results. The averaged power density of measurement is normalized by the value evaluated in calculation without phantom. The experimental result of SAR is 0.056 W/kg in the proposal method and 0.0516 W/kg in the standard FDTD analysis. In this measured result, an increase of about 10% is expected when compared with calculations for whole-body averaged SAR. This variation is caused by low presumption of radiated power due to using the limited height of the cylindrical scanning area. By increasing the height of the cylindrical scanning area, more improved estimation results will be obtained.

Based on the cylindrical field scanning technique, a new whole-body averaged SAR estimation method that is appropriate for developing the experimental system is proposed. Moreover, the actual experimental set-up is constructed, and some measurement results of whole-body averaged SAR for plane-wave exposure is reported.

Acknowledgments

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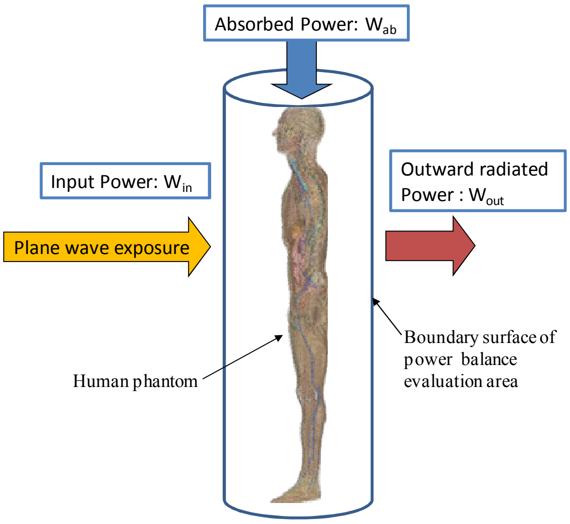

Figure 1: Proposed Whole-body Averaged SAR Estimation Method

Table 1: Phantom Parameters

Frequency	1. Full -size : 2000 MHz 2. ½scaled : 4000 MHz	
Phantom size and weight	1.	height: 180 cm wight:68.55 kg
	2.	height: 90 cm weight:8.54 kg
Material	2/3 muscle equivalent tissue (Homogeneous)	
Tissue's parameter	1.	ε_r :36.0 σ:1.04 S/m
	2.	ε_r :36.0 σ:2.1 S/m

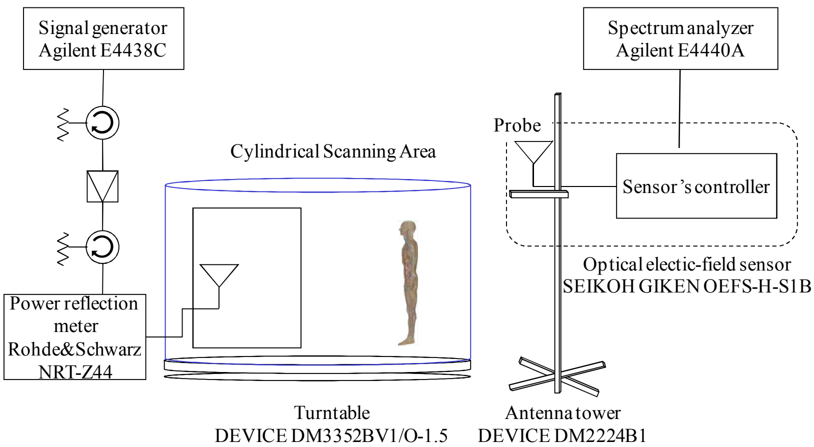

Figure 2: Block Diagram of the Experimental Set-up for Whole-body Averaged SAR Estimation using Cylindrical Scanning

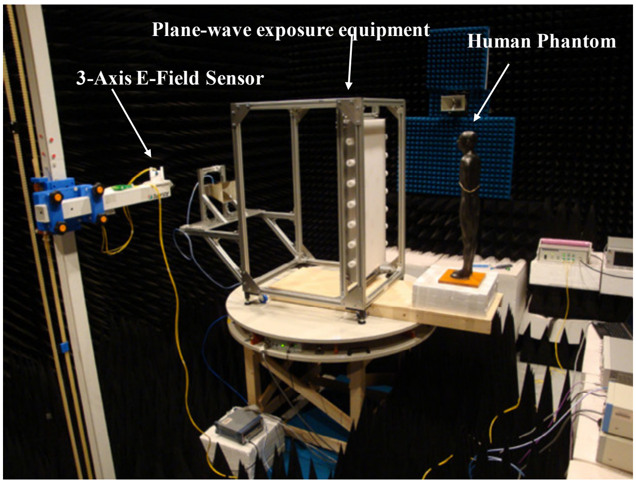

Figure 3: Developed Experimental Set-up in Anechoic Chamber

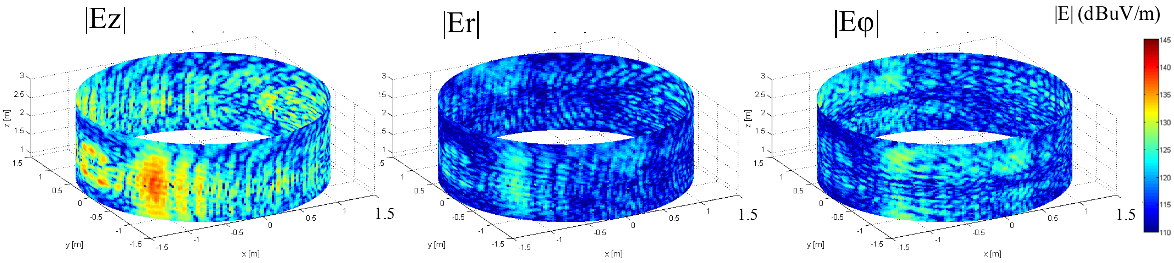

Figure 4: Example of Measured Electric Field Distributions on Cylindrical Scanning Area

Table 2: Absorption Power and Whole-body Averaged SAR of European Adult

	Measurement	FDTD Result based on IEEE 1528a
Normalized Absorbed power [W]	0.948	-
Whole-body Averaged SAR [W/kg]	0.056	0.0516

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